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Usefulness of intraoperative transcranial sonography in patients with traumatic brain injuries: a comparison with postoperative computed tomography

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Purpose: The aim of this study was to assess the agreement between intraoperative transcranial sonography (TCS) and postoperative computed tomography (CT) in patients with traumatic brain injuries.

Methods: We performed a retrospective cross-sectional study of 35 patients who underwent TCS during surgery, among those who presented to a regional trauma center and underwent decompressive craniectomy between January 1, 2017 and April 30, 2020.

Results: The mean difference between TCS and CT in measuring the midline shift was –1.33 mm (95% confidence interval, –2.00 to –0.65; intraclass correlation coefficient [ICC], 0.96; $P<0.001$). An excellent correlation was found between TCS and CT in assessing contralateral subdural hematomas (ICC, 0.96; $P<0.001$) and focal hematoma lesions (ICC, 0.99; $P<0.001$). A very good correlation between TCS and CT was found for measurements of ventricle width (ICC, 0.92; $P<0.001$).

Conclusions: TCS during surgery is considered an effective diagnostic tool for the detection of intraoperative parenchymal changes in patients with traumatic brain injuries.

Keywords: Traumatic brain injuries; Intracranial pressure; Decompressive craniectomy; Ultrasonography

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INTRODUCTION

Intracranial hemorrhage is a life-threatening crisis that can appear after an acute traumatic brain injury (TBI). Massive hematoma causes a rise in intracranial pressure (ICP), which can result in brain injury, a permanent vegetative state, or death. Decompressive craniectomy (DC) is performed to reduce ICP; in rare cases, this can result in the appearance and expansion of a contralateral hematoma after surgery. If this possibility is neglected, a poor prognosis may occur [1–5].

Imaging is a necessity of the TBI diagnostic process, and computed tomography (CT) is the most significant test in the acute posttrauma phase [6]. Due to advances in ultrasound technology over the past decade, several authors have well visualized adult cerebral arteries, veins, parenchyma, and ventricular systems through a transtemporal approach using B-mode ultrasonography [7–10].

Therefore, we hypothesized that transcranial sonography

(TCS) during DC procedures could be used to evaluate brain anatomy. To test the hypothesis, the consistency between TCS during surgery and postoperative CT was evaluated and visualized in terms of the diameter of focal hematoma lesions, lateral ventricle, contralateral subdural hematoma (SDH), and midline shift (MLS).

METHODS

Ethical statements

We investigated patients who presented to the hospital and underwent DC between January 1, 2017 and April 30, 2020. A retrospective cross-sectional study was performed of 35 patients who had a small amount of SDH present on the opposite side in the initial CT scan and underwent TCS during surgery. The study was approved by the Research Ethics Board of the Pusan National University Hospital (No. 2008-003-093). Since both ultrasound and CT scans are part of routine practice for patients during surgery at our hospital, written informed consent was not required. Postoperative CT was evaluated by a neuroradiologist and compared with the TCS results.

Technical methods

TCS was performed by a single operator using a GE logiqE device (GE Healthcare, Milwaukee, WI, USA) and a standard abdominal convex phased-array probe with an average median frequency of 4 MHz and abdominal settings. A dynamic range of 45 to 50 dB was used. After applying a small amount of sterile ultrasound gel, the probe was gently placed on the dura mater so that the ICP did not increase. Scanning was performed at a depth of 16 cm, and the entire brain was scanned in B-mode (Fig. 1).

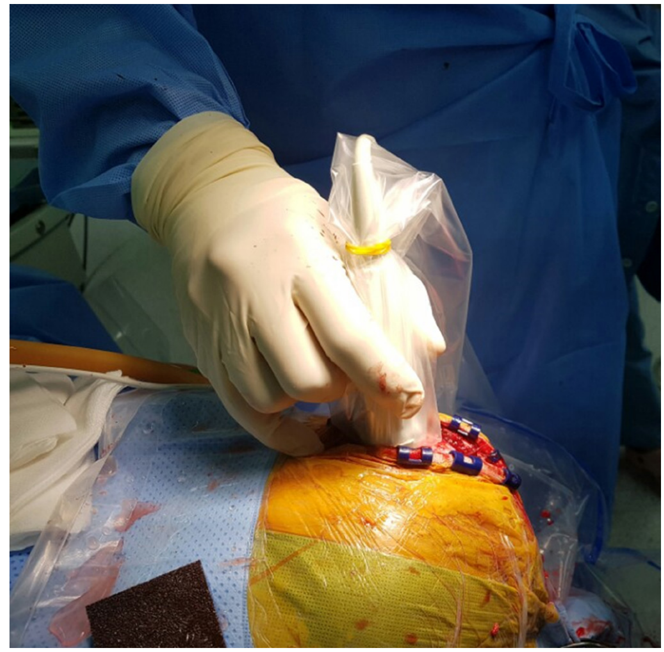

Fig. 1. Transcranial sonography was performed during surgery.

Midline structure shift

In the axial plane, the midline was evaluated as the line between the two lateral ventricles. After localizing the falx cerebri in the frontal lobe, the distance between the septum pellucidum and the lateral margin of the right ventricle was measured. The distance between the septum pellucidum and the lateral margin of the left ventricle was measured in the same way (Fig. 2A). The difference between the two measured values is the MLS. The consistency between CT and TCS was investigated.

Evaluation of focal hematoma lesions

Intracerebral hemorrhage (ICH) appears as a homogenous, sharply demarcated mass on TCS. We measured the maximum diameter of this mass (Fig. 2A). Focal hematoma lesions are divided into low density and high density according to their density on CT scans. The maximum diameter of ICH confirmed as having high density in the axial plane of the CT scan was measured (Fig. 2B). We investigated the consistency between CT and TCS in evaluating the diameter of the main axis of high-density lesions.

Evaluation of contralateral subdural hematoma lesions

The depth of the contralateral SDH was measured through intraoperative TCS and postoperative CT scans (Fig. 3A, B). We compared the depth measurements between the two devices.

Evaluation of the ventricular system

In patients with an intact skull, the lateral ventricle was studied using the method described by Seidel et al. [11]. By moving the ultrasound beam slightly upward from the midbrain plane, the frontal horn of the lateral ventricle can be detected. The lateral ventricle was always easily visualized by TCS. The distance between the body of lateral ventricle and septum pellucidum was measured (Fig. 2A, B).

Statistical analysis

For statistical analysis, MedCalc ver. 18.11.6 (MedCalc Software, Ostend, Belgium) was used. To study the consistency between CT and TCS in measurements of the MLS, focal lesion size, and the size of the lateral ventricles, the paired t-test or Wilcoxon

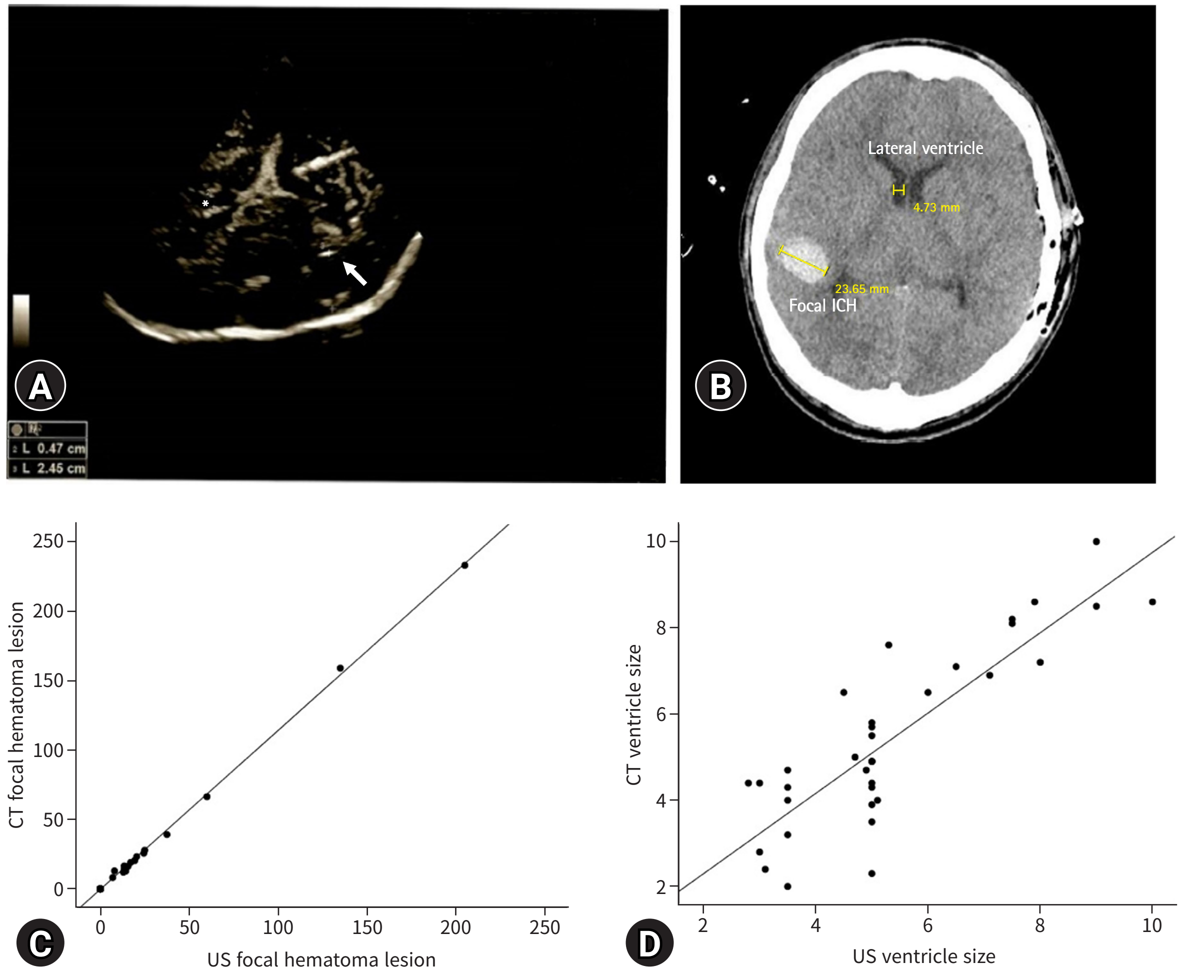

Fig. 2. The frontal horns of the lateral ventricle (asterisk) and focal hematoma lesion (arrow) on (A) transcranial sonography and (B) computed tomography (CT) are shown. An excellent linear correlation was found between CT and transcranial sonography in the diameter of (C) the focal hematoma lesion and (D) ventricle size. ICH, intracerebral hemorrhage; US, ultrasonograhpy.

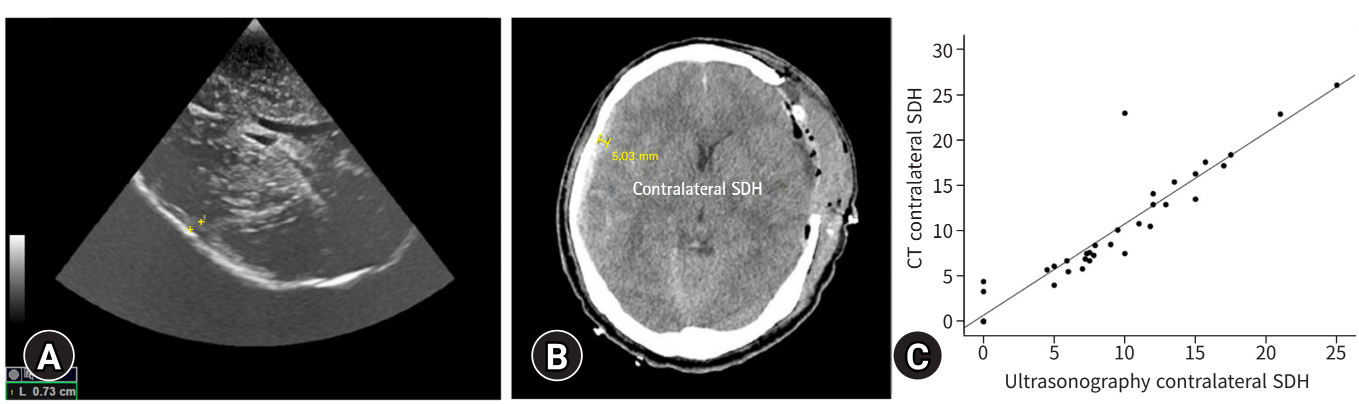

Fig. 3. A subdural hematoma (SDH) was clearly visible on (A) transcranial sonography (TCS) as a hyperechogenic lesion (between the two plus signs) on the opposite side of the craniectomy. (B) A corresponding computed tomography (CT) is shown. (C) An excellent linear correlation was found between CT and TCS in the diameter of the contralateral SDH lesion.

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signed-rank test was performed depending on whether the data satisfied the assumption of a normal distribution. The consistency between the techniques was assessed by Bland-Altman plots and intraclass correlation coefficients (ICCs), with an ICC of 0.75 indicating a good correlation. A P-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Midline shift

MLS was found on TCS in 31 cases. All cases were confirmed on CT, and a good correlation between these two techniques was found (Table 1). The mean difference between the two methods was –1.33 mm (95% confidence interval [CI], –2.00 to – 0.65), the ICC was 0.96 (95% CI, 0.88 to 0.99), and no systematic bias was observed in the Bland-Altman plot (Fig. 4).

The diameter of the focal hematoma lesion

In 16 patients, lesions were observed on TCS scans (Fig. 2A). All high-density lesions were visualized on CT (Fig. 2B), and a good correlation was found between TCS and CT (Table 1). The mean diameter difference between the two methods was –2.21 mm (95% CI, –4.32 to –0.09), the ICC was 0.99 (95% CI, 0.99 to 1.00), and no systematic bias was observed in the Bland-Altman plot (Fig. 2C).

Depth of the contralateral subdural hematoma lesion

In 35 patients, lesions were observed on TCS scans (Fig. 3A). All high-density lesions were visualized on CT (Fig. 3B), and a good correlation was found between TCS and CT (Table 1). The mean diameter difference between the two methods was – 0.77 mm (95% CI, –1.64 to 0.09), the ICC was 0.96 (95% CI, 0.92 to 0.98), and no systematic bias was observed in the Bland-Altman plot (Fig. 3C).

Evaluation of the ventricular system (ventricle size)

A very good correlation was found between TCS and CT (Table 1). The mean difference between the two methods was –0.07 mm (95% CI, –0.44 to 0.30), the ICC was 0.92 (95% CI, 0.84 to 0.96), and no systematic bias was observed in the Bland-Altman plot (Fig. 2D).

DISCUSSION

It is rare for a new hematoma to form on the contralateral side after hematoma removal or for an existing hematoma to expand. The causes of hematoma growth are rupture of a meningeal artery branch, low-tension bleeding, or venous laceration that causes a skull fracture [1]. In general, neurological deterioration, pupillary dilation in response to hematoma, seizure, and intractably increased ICP are critical signs of *de novo* hematoma formation or volume expansion of a contralateral hematoma after surgery [5,12]. Neurosurgeons depend on CT scans after surgery when he-

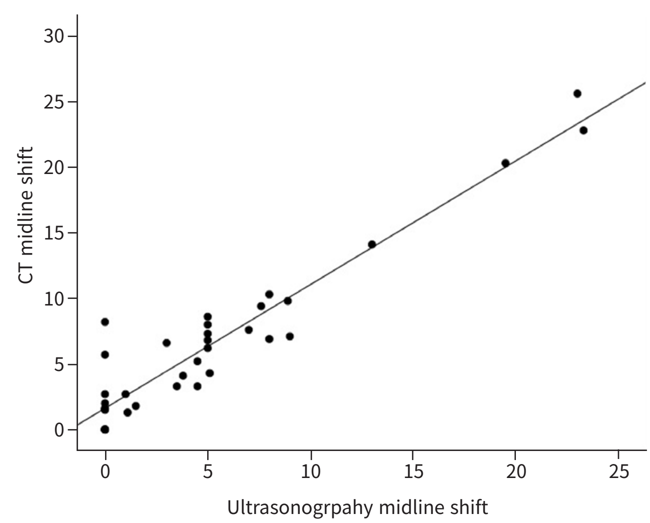

Fig. 4. An excellent correlation was found between midline shift measured on transcranial sonography and on computed tomography (CT).

Table 1. Results of clinical tests

Clinical test	TCS	CT	Mean difference (95% CI)	ICC (95% CI)	P-value[a]
Midline shift (mm)	5.15±6.23	6.48±6.18	–1.33 (–2.00 to –0.65)	0.96 (0.88 to 0.99)	<0.001
Focal hematoma lesion (mm)	17.97±41.08	20.18±47.05	–2.21 (–4.32 to –0.09)	0.99 (0.99 to 1.00)	<0.001
Contralateral SDH lesion (mm)	9.04±6.17	9.82±6.72	–0.77 (–1.64 to 0.09)	0.96 (0.92 to 0.98)	<0.001
Ventricle size (mm)	5.35±1.87	5.42±2.04	–0.07 (–0.44 to 0.30)	0.92 (0.84 to 0.96)	<0.001

Values are presented as mean±standard deviation.
TCS, transcranial sonography; CT, computed tomography; CI, confidence interval; ICC, intraclass correlation coefficient; SDH, subdural hemorrhage.
[a]Statistically significant ICC.

matoma formation or expansion is predicted, such as in patients with previous contralateral cranial fractures or hematomas or severe brain escape after removal of the ipsilateral hematoma [1].

Early identification and decompression of the contralateral hematoma can reduce the secondary insult to the normal brain but may lead to safety issues related to CT scanning, surgical wound closure, and transport to the CT room [1]. Some authors have suggested exploratory burr-hole trephination on the other side during the first operation [12], but this is regarded as too invasive a way to prove the probability of hematoma expansion or formation. CT during surgery is an excellent diagnostic tool that is used at some institutions, but it has many limitations, such as economic considerations, preparation and surgical time, and the risk of radiation exposure [1]. Therefore, TCS was considered as an alternative diagnostic tool for TBI patients during surgery, and this study was conducted to confirm the consistency of the results.

The main finding of this study was that TCS during surgery was effective in evaluating ICH, MLS, contralateral subdural hemorrhage, and the dimensions of the ventricular system in patients with DC, just like CT. With ongoing developments in ultrasound technology, TCS has been regarded as a reliable tool to evaluate brain parenchyma in patients with an appropriate acoustic temporal window [7,8,13,14]. In 1993, Becker et al. [14] first reported an accurate functional description of the ultrasound portrayal of brain anatomy; subsequently, several authors have found similar results, and TCS has been extensively studied in many other contexts, such as cerebral perfusion imaging [15–19]. However, few reports have described the application of TCS during DC surgery [20–22].

TCS during surgery has some benefits as a diagnostic tool. First, it can provide meaningful images of the brain. Precise functional descriptions of the ultrasound portrayal of brain anatomy have been given in the literature. Some reports have suggested that low-frequency probes can be used to detect hematoma, intermediate line movements, and ventricle enlargement in the temporal bone of an intact skull [16,17,23,24]. The quality of the lateral images of DC patients is good and the accuracy is not compromised by epidural implantation [20–22]. Furthermore, after bone flap removal, the frequency of the probe may be higher than that of TCS [25]. Thus, an excellent image of the surface area of the brain parenchyma can be acquired. Furthermore, in the event of a large amount of brain herniation during surgery, TCS can be specifically effective in distinguishing various ipsilateral pathologies that require surgery, such as brain hematoma with edema or SDH.

Second, TCS during surgery decreases the time and effort required for imaging compared to postoperative CT and does not need surgical wound closure and transport to the CT room. The application of TCS also decreases the risk of patient aggravation during transport and reduces the time needed for decision-making.

Third, the apparatus required for TCS during surgery is quickly accessible at most institutions. Ultrasonography is generally used by anesthesiologists and can be converted to B-mode ultrasonography by adding a probe to the Doppler sonography machine, which is widely used in neurovascular surgery. Furthermore, TCS has no hazard of radiation exposure to patients or health care providers.

Fourth, when planning an operation to remove a hematoma or insert an instrument for intraventricular pressure measurement when ICH is confirmed on preoperative CT, most of them use navigation CT to determine the location of the lesion or ventricle before and during surgery [26]. However, in patients who have undergone DC, there may be an error in the navigation system due to the phase difference of the parenchyma between the CT image before surgery and the skull after removal. In this case, the location of the hematoma can be reconfirmed using TCS. Also, the insertion of an intraventricular pressure measurement device can be safely performed under TCS guidance.

However, a disadvantage of TCS during surgery is that the image quality is limited compared to that of CT. Caricato et al. [23] described the nonvisualization of low-density ischemic lesions and the posthemorrhage stage in CT scans in 11 patients monitored using bedside TCS. Niesen et al. [24] reported that three out of 25 SDH cases (12%) were missed when using TCS as a poor temporal bone window. TCS also has more limited visibility than CT, so the operator must tilt and move the probe to obtain a complete image of the brain [23,24]. As reported by Kim et al. [1], an epidural hematoma on the opposite side of the frontal lobe may be missed if clinicians do not anticipate the presence of a hematoma due to the presence of an existing left frontal fracture. Since TCS is a user-dependent technique, the operator should be properly trained in accurate evaluation of the brain.

Therefore, TCS cannot completely substitute for CT. Nevertheless, we suggest that TCS during surgery may be an effective diagnostic tool, especially in cases of TBI when time-consuming assessments are limited because of possible systemic compromise and the need for prompt decision-making. Prospective studies are needed to improve our understanding of the usefulness and limitations of TCS compared to CT.

In this study, due to the small number of enrolled patients,

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there are some limitations in comparing CT and TCS. We compared and analyzed MLS, focal ICH, contralateral SDH, and ventricle size. The results of TCS showed statistical significance when compared with CT. TCS during surgery is considered an effective diagnostic tool for the detection of intraoperative parenchymal changes in TBI patients.

NOTES

Ethical statements

The study was approved by the Research Ethics Board of the Pusan National University Hospital (No. 2008-003-093). Since both ultrasound and computed tomography scans are part of routine practice for patients during surgery at our hospital, written informed consent was not required.

Conflicts of interest

The authors have no conflicts of interest to declare.

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None.

Author contributions

Conceptualization: BCK; Data curation: MH, JHL; Methodology: HJC, BCK; Writing–original draft: MH, BCK, JHL; Writing–review & editing: SHY, HJC. All authors read and approved the final manuscript.

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